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TEN YEARS' DEVELOPMENT OF METALLURGICAL RESEARCH AND TECHNOLOGY  
IN COMMUNIST CHINA

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TEN YEARS' DEVELOPMENT OF METALLURGICAL RESEARCH AND TECHNOLOGY  
IN COMMUNIST CHINA

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Li Hsun

Metallurgy has had a long history in our country. Our ancestors made outstanding contributions in this field toward the civilization of mankind since time immemorial. However, because the feudal system lasted in our country for more than two thousand years, production did not move forward, and, as a consequence, ancient science and technology were not developed to the extent possible. During the last hundred years, our country was left even farther behind because of imperialistic oppression.

After New China was established, under the correct leadership of the Party, in line with the policy of developing basic industries, learning from the advanced experience of the Soviet Union, and getting assistance from the Soviet Union and other brother countries, we established our own metallurgical industry. In ten years, steel production has been raised from the 158,000 metric tons in 1949 to 12,000,000 tons this year, and the nonferrous metal industry has been developed to sizable proportions from a very weak base. The work in metallurgical science and technology has been primarily oriented around raising production and meeting the needs of rapid progress in industrial construction. The progress and achievements in our country's metallurgical science and technology during the last ten years are discussed below from different approaches.

A. Coordinated Utilization of Resources

To meet the needs for constructing a new iron and steel base, we have made investigations on a certain type of iron ore containing fluorine. This type of iron ore contains rare earth minerals and fluorite. The deposits in question have many special characteristics with regard to geological structure, origin of ore bodies, and composition of minerals. Workers engaged in ore beneficiation established three types of flow-sheets to solve the milling problems. The methods are magnetic separation combined with flotation, roasting followed by magnetic separation in

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combination with flotation, and reverse flotation. In each process, the iron concentrate made contains 60% Fe or better, recovery is more than 80%, and fluorine content is reduced to about 1%. Thus, smelting specifications are met.

The smelting of fluorine-bearing iron ore is a new technique in metallurgical practice. Therefore, a whole series of metallurgical tests must be made in large industrial scale blast furnaces. Blast furnace tests indicate that most of the fluorine in the ore enters into the slag with the effect of reducing the viscosity and melting point of the slag; thus, a highly basic slag is permissible in blast furnace operations on this type of ore. We discovered that the presence of fluorine has little effect on the distribution of sulfur in the slag and iron melt. By raising the basicity of the slag under appropriate smelting conditions, the sulfur in the pig iron produced can be cut down greatly while maintaining smooth blast furnace operations.

Investigations on the corrosion effect on refractory materials of blast furnaces by fluorine-containing furnace gases and fluorine-containing slag show that the behavior of fluorine materials is rather complicated during blast furnace operations. When the temperature in the blast furnace drops to the vicinity of 1,000°C, the fluorite in the iron ore decomposes markedly to form HF which rises through the charge with the furnace gases; on ascending, part of the HF is then adsorbed by the relatively cool lime or limestone and follows the charge down again. When the iron ore and other fluorine-containing furnace charge materials descend to the slag forming zone, the fluorine materials first enter the melt and, then when the temperature rises, escape with other materials formed and once more ascend with the blast furnace gases upward through the charge. It is thus seen that the corrosion effect of fluorine materials on the blast furnace linings varies with the different positions in elevation. When the HF content of the furnace gases is less than 0.1% and when the temperature is between 500 and 900°C, the corrosion effect of fluorine materials on alumina-silicate refractories is very small. The rate of corrosion of fluorine-bearing molten slag on refractory linings is related according to an index formula with the rise in temperature; however, for molten slag containing less than 10% fluorine, the higher the alumina content of the refractory the less the dissolving or corrosion effect. Corrosion by  $\text{CaF}_2$  on various grades of high-alumina brick starts to become severe when the temperature exceeds 1,200°C. Experiments in large size blast furnaces indicate that even high-alumina brick cannot prevent corrosion by fluorine-containing molten slag and therefore carbon brick must instead be used.

In the investigations on coordinated utilization of fluorine-bearing iron ores, methods have also been devised with regard to processes and techniques to extract or recover rare earth alloys from tailings and blast furnace slag. The question of separating various rare earth elements has also been studied.

In treating oxide copper in copper-bearing iron ore, the fluidized bed-sulfate roast-hydrometallurgical method is used; the copper in the final solution is precipitated by iron and over-all copper recovery is more than 80%. Another method is the chloridized roast so as to cause the volatilization of copper; 90% of the copper can be volatilized; however, the solidification and recovery copper chloride on an industrial scale must still be further investigated.

Our country's vanadium and titanium-bearing iron ores are very extensive. The rational utilization of certain types of vanadium and titanium-bearing iron ores has already been solved. Investigations are now being made on other types of vanadium-titanium-iron resources.

To enable more economic and rational utilization of lean iron ores, investigations are being made in our country on a special roasting furnace embodying the combined principle of conducting heat in the dilute phase and causing reaction in the concentrated phase. Preliminary studies show that for 35% Fe hematite iron ore from Anshan processed by the above described magnetizing roasting method, a magnetic separation concentrate analyzing 65% Fe can be produced at an iron recovery rate of 90%.

To solve the problem of ores containing relatively high and variable quantities of phosphorus, our country started to develop the technique of using the side blown basic converter to smelt steel soon after the liberation. As a result of several years of experience, we have made many improvements both in the structure and in the operations of the converter. Pig iron containing 0.2-1.6% phosphorus can be processed into steel that meets specifications.

In the field of refractory materials, high alumina brick is being used to an increasing extent because of the existence of extensive resources of aluminous materials. When high alumina brick is used for the tops of electric furnaces, it lasts several times longer than silica brick. We have drawn many conclusions from our investigations on the manufacture of high alumina brick. The burning together of the aluminous materials to make refractory brick is intimately related to the  $\text{Al}_2\text{O}_3$  content and the  $\text{Al}_2\text{O}_3/\text{SiO}_2$  ratio, and the amount of secondary Mo-lai stone formed has a definite effect on the sintering reaction. The existence of small quantities of iron and titanium oxides accelerates the

burning together of the aluminous materials; the temperature needed to make the refractory brick is lower when the aluminous materials are in fine or broken form. Another achievement with regard to refractory materials is the use of alumina-magnesia brick in place of chrome-magnesia brick; this substitution helps to relieve the present shortage of chrome ores in our country. Through the use of alumina-magnesia brick, the furnace top linings of the stationary top medium-size open hearth furnace lasted as much as 623 heats and the furnace top linings of the "inclined moving" /suspended arch?/ top large size open hearth furnace lasted as much as 520 heats; thus, the effectiveness of alumina-magnesia brick approaches that of chrome-magnesia brick. In order to stabilize and improve the quality of alumina-magnesia brick, we have systematically studied various techniques and constituents as affecting the characteristics of the alumina-magnesia brick. We investigated the effect of adding spinel, the composition and changes of the alumina-magnesia brick during use, and the main causes for the corrosion of the brick. From all these investigations, we determined the rational technique for making suitable alumina-magnesia bricks.

In the field of nonferrous metals, we used to recover only copper, lead, and zinc from complex sulfide ores containing copper, lead, zinc, iron, etc., while ignoring other recoverable values. The approach has been different since the liberation. We strengthened analytical work, improved operational flowsheets, and made careful investigations on processing various types of primary and waste materials, including crude ore, tailings, mine dumps, flue dust, furnace slag, slimes, intermediate products, rejected solutions, and return solutions. This work has enabled us to produce greater quantities and varieties of rare metals. We paid particular attention to ore type and co-existing minerals, adopted many coordinated beneficiation methods, established flowsheets combining milling with hydrometallurgy, solved problems of many complicated minerals from a viewpoint of an integrated approach toward recovering all the useful values, and, at the same time, were able to improve the recovery of the metals previously extracted. For example, from tungsten ores, we are recovering molybdenite, bismuthinite, chalcopyrite, cassiterite, scheelite, pyrite, and other useful constituents. Similarly from tin ores we are recovering lead, copper, tungsten, iron, zinc and other metals. Fair success has also been achieved in other fields, and we are continuing investigations on the integrated approach for recovering all useful values. With regard to smelting and refining, we can say that from smelting and refining of copper, lead, zinc, and tin alone, eighteen useful materials are being recovered at present.

In the field of smelting and refining of light metals, it was necessary to find new processing methods to treat the types of aluminous ores found in our country, which belong to the hard-to-dissolve category (mostly diasporic) with silica content as high as 17%. As a result of

investigations, we finally decided to adopt the chain-connected combination method to process the aluminous ores. The method involves the use of concentrated caustic solution plus lime as accelerating reagents, dissolving on the principle of the Bayer Process but at 26 atmospheric pressures, and processing the residue by sintering; a 95% alumina recovery has been achieved by this method. The reason why sintering is an important step in treating high silica raw materials is that the low solubility calcium silicate formed by the limestone and silica in the aluminous ore is utilized to avoid the large losses of soda and alumina which normally result from the conventional Bayer Process as applied to high silica aluminous ores. However, the calcium silicate, after the cooked material is dissolved out, can have a secondary reaction with the sodium aluminate solution to cause losses in alumina and sodium oxide. Therefore, we investigated the problem of how to minimize or prevent the secondary reaction mentioned above. We found that the main product or derivative from the secondary reaction is hydrated garnet, which has the formula  $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot n\text{SiO}_2 \cdot (6-2n)\text{H}_2\text{O}$ ; in addition, some sodium aluminum silicate ( $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot m\text{SiO}_2 \cdot n\text{H}_2\text{O}$ ) is formed. When the concentration of the dissolved solution with respect to sodium hydroxide and sodium carbonate ion content is reduced, the red mud particles have a tendency to coagulate so as to cause an increase in precipitate volume and slow down secondary reaction. The above experiments show that when the cooked material is dissolved out in two parts and the caustic soda ration in the sodium aluminate solution is reduced to about 1.25, a secondary reaction is almost stopped. Calculating on the basis of the residue finally rejected, the net amount dissolved reaches 92-93%.

#### B. Strengthening Operational Procedures to Raise Production

The accomplishments resulting from strengthening ferrous and ferroalloy metallurgy are clearly shown in the steady rise of utilization coefficients for blast furnaces, open hearth furnaces, and electric furnaces.

During 1951, the national average utilization coefficient for medium and large size blast furnaces was 1.608; by 1958 the figure had risen to 1.437, and for some advanced units such as the Pen-hsi Iron and Steel Company blast furnaces the utilization coefficient was maintained at above 2.1 for the whole fourth quarter of 1958, and was raised to above 2.44 in May of 1959. The technical measures to strengthen blast furnace smelting were generally along these lines: improve the preparation of the raw materials, including even mixing of the charge, charging or loading according to material size, making of ball-shaped pellets, introducing self-agglomerating sintered ore, etc.; employ the top of the furnace for regulatory purposes; introduce the system of using more draft and at higher temperatures; moisten the air blown in to a greater

extent; adopt high pressure techniques; and improve the slag formation systems. However, the main reason why our country's blast furnaces have been able to achieve outstanding results is that we have mastered the techniques related to the above described measures. We dared to raise the draft temperature and volume and increase the smelting intensity; we also made improvements along all other lines; as a result, blast furnace operations have been very smooth and the coke consumption ratio has been reduced. Results prove that we have taken the correct approach toward raising output in blast furnaces. At the present time, our country's high production blast furnaces, such as Pen-hsi, Anshan, Tai-yuen, etc., are all employing a wind or draft temperature of about 1,000°C.

Past experience has shown that when greater quantities of air are introduced to normally operating blast furnaces, an overblown phenomenon often results so that steady operations are disrupted, charges might become suspended, and furnace abnormal growths might occur. Raising the temperature of the dry air might cause the combustion zone to become smaller and the slag formation zone to be lowered with the result that steady operations might also be disrupted. At the same time, the coke consumption ratio might rise when the smelting intensity is increased. For the reasons described above, there are definite limitations in the intensity of smelting for blast furnaces, which was, in the past, 1.1 for large blast furnaces and 1.2 for small blast furnaces. Prior to 1957, the conditions for preparing the charge and the techniques related to blast furnace smelting in our country were affected by the above described limitations. In the great leap forward of 1958, our country's blast furnace workers made further improvements on preparing the raw materials for blast furnace operations according to the principle of increase of air must correspond with ease of air passage in the charge; we were able to increase the smelting intensity while maintaining successful normal operations. In actual practice, after the smelting intensity is raised to a new level, we then look for conditions that make for the lowest coke consumption. In this manner smelting intensity can be steadily raised, and, when conditions are right, coke consumption can be lowered. For example, the Pen-hsi blast furnaces had the smelting intensity gradually raised from 1.013 in 1957 to 1.4-.15 in 1958 (the furnace utilization coefficient was raised 33.8%); nonetheless, the coke ratio was reduced 10.8%. Again for example, the Taiyuan blast furnaces had the smelting intensity gradually raised from 1.003 in 1957 to 1.201 in 1958 (the furnace utilization coefficient was raised 33.8%); nonetheless, the coke consumption ratio was lowered 15.7%.

The experience on blast furnace operations since the leap forward shows that as the smelting intensity is raised the air velocity was also increased. However, when the draft is too rapid and intense, a bad distribution of coal gas will result; it is necessary to regulate the gas in the top and bottom parts of the blast furnace very carefully to assure efficient smelting. At the Pen-hsi Iron Smelting Plant, by



increasing the diameter of the air opening or tuyere, which had the effect of reducing the speed of the inflow of air so that the coal gas distribution became more even in the furnace, the smelting intensity was raised from 1.338 to 1.542. For a blast furnace of the Taiyuan Iron and Steel Company, through reducing the weight of each charge, changing the loading systems for the charge in order to regulate the air circulation in the corner parts, and gradually adding more self-agglomerating sintered ore, the smelting intensity has been raised to more than 1.4. While increasing the temperature of the dry air, the volume of coke can be correspondingly increased to help absorb the additional heat brought into the furnace by the hot air. Experience has shown that the measures described not only improve blast furnace operations but also will reduce the coke consumption ratio.

With regard to steel refining, the national average utilization coefficient has been raised from 4.6 in 1952 to 7.81 in 1958; for the advanced Shang-kang san-ch'ang (Shanghai Iron and Steel Company No. 3 Plant?) the utilization coefficient of the open-hearth furnaces reached as high as 13.0. The national average utilization coefficient for cold-charged electric furnaces was 6.67 in 1952, 17 in 1957, and 22.6 in 1958; for the advanced Dairen Steel Plant, this coefficient was more than 30. Measures to increase production in open hearth and electric furnace operations have been along the lines described below:

1. Reduction in the time of stoppage of furnaces and an increase in the operational rate -- Chrome-alumina bricks or Magnesite-alumina bricks, which are basic refractories, are used for the tops of the open hearth furnaces. The water-cooled parts have been changed to the steam-cooled system. Thick layers of charge are employed. The sheet iron fused furnace bottom system is used. We have learned the fused furnace bottom method from the Soviet Union and believe the method has the following definite advantages: (a)  $\text{FeO}$  can, under relatively low temperatures and within a short time period, completely melt into  $\text{MgO}$  and form a continuous solid molten body so that magnesium sand grains grow in size and air openings are filled; and (b) under oxidized conditions the magnesium ferrite formed also helps to develop the  $\text{MgO}$  grains so as to further seal up the air openings. With regard to electric furnaces, the principal measures to reduce stoppage time are the use of high alumina brick for the furnace tops and the holding in reserve of additional furnace bodies.

2. Installation and loading of furnace -- Changes have been made in the furnace body and in the auxiliary facilities of the open hearth furnaces. The furnace top is raised, the furnace bottom is made thinner, the ascending route is enlarged, the chimney is made higher, the hoisting system is strengthened, and the containers for holding the steel are raised in height. In addition, we adopted the two-stream or three-stream molten steel discharge system, which lightens the load of the

hoisting system. At the present time, our country's 15 square meter furnace bottom small open hearth furnaces can take a charge of 60 metric tons, whereas 94.5 square meter furnace bottom large open hearth furnaces can take a charge of 660 tons. With regard to electric furnace installation and loading problems, we first looked into how to make best use of the latent capacity of the transformers; by using more durable transformer oil, we were able to improve transformer performance by 30%. Second, after an electric furnace is charged, it becomes difficult to raise the temperature of the melting or smelting zone; by blowing in oxygen, the temperature of this zone can be raised.

3. Reduction in the smelting time -- To achieve this objective in open hearth furnace operations, we increased the heat and reduced the boiling time; for ordinary steels, we also eliminated the preliminary step of oxygen removal. In electric furnace operations, the most important step taken to cut down on smelting time was the addition of oxygen during the process of steel refining. Smelting time can be reduced by 15-20 minutes when pure oxygen is blown in; it can be cut by half in hour when a coal gas oxygen mixture is blown in. When large quantities of oxygen are used to facilitate smelting, phosphorus can be removed faster and the purifying and boiling period can be greatly shortened. By using carbide slag that has been directly reduced or carbide slag that first underwent oxygen removal through addition of silicon manganese alloys to get rid of oxygen in the steel, the reducing period of the electric furnace can be cut down to 50 minutes or less. The above described results of research have already been widely applied in our country's electric steel operations; these practices have been important in raising electric steel output.

4. Adoption of new techniques -- In addition to applying foreign combination steel smelting and refining techniques, such as the combination open hearth-electric furnace method and the electric furnace-electric furnace method, we are also investigating the combination technique of using the converter together with the electric furnace. Our experiments show that when converter steel is processed with electric steel and slag, the nitrogen and hydrogen content of the product are low and other impurities are not much different from those found in the single process electric furnace steel. The converter-electric furnace combination method of refining steel seems to have a bright future from the viewpoint of increasing the production of certain good quality steels. Continuous ingot casting improves the utilization rate of the steel ingots. In recent years some steel plants and research organizations in our country have started to make investigations along these lines; they have developed vertical continuous ingot casting machine as large as 210x210 mm in cross section that has a drawing speed of 0.5-5.0 meters per minute, and they have made other studies on ingot casting techniques. Because a vertical type continuous ingot casting

plant requires relatively large capital investments. Experiments were also done on horizontal and inclined types of continuous casting machines. An inclined machine of 30° with a cross section of 100x100 mm has proven satisfactory in the experimental stage and preparations are being made to try it out on an industrial scale.

In the field of rolled steel, blooming is by the double ingot system with enlarged capacities and improvements in bloom pass design are based upon the principle of reducing the number of passes in forming steel shapes; the changes made have resulted in steady increases in capacities as compared with the original rated capacities, production rates at present being two to five times those of 1949 for the same types of equipment. In the past our country used the parallel-lined rolling mill system to make round steel and wire materials of 12 mm or smaller; only the regular plates were used and the directing of elliptical-shaped rolled material into square or round openings had to be done by hand with long tongs. In 1958 a certain plant developed a simple and light plate structure and improved the guide plates where the rolled steel enters. Even 6.5 mm wire materials can be directed into the openings with this kind of plate and many strings can be made simultaneously. Prior to this, the tendency to make wire mills is to make them work continuously; however, the continuous type of mill is heavy, requires large electric motor units, and involves capital investments several times those of parallel-lined rolling mills. The development of the above described plate will promote the use of the parallel-lined rolling mill system.

In the field of metal mining, improvements have been made in extraction methods, in applying new types of equipment and facilities, in blasting techniques, in excavation of shafts and tunnels, and in over-all mining efficiency. In underground mining, productivity in 1958 was about three times greater than in 1952. In addition, working conditions in mines have been greatly improved.

Beneficiation and smelting and refining of nonferrous metals have been greatly strengthened, as indicated in the rise in recovery rates as well as other technical and economic cost indices. To achieve this over-all objective, the work in recent years has been along these general lines:

(a) Advanced techniques have been disseminated -- In the field of ore-dressing, by using grinding and milling in many sections, tin recovery has been raised 5%; and by using heavy-media separation, large quantities of associated metals found in tungsten and tin ores have been recovered. In the field of smelting and refining, fluosolid roasting and hydrometallurgy (including dissolving and extraction at high pressures, inorganic extraction, use of ion exchange methods, etc.) have

been widely applied. For example, difficult-to-mill copper oxide ore containing high iron in fine particles is treated by sulfate roasting and hydrometallurgy with the recovery of 96% of the copper. Again for example, a copper oxide ore containing high copper and magnesium is dissolved in ammonium solutions under high pressure with the recovery of 85% of the copper.

(b) New types of equipment have been used -- With regard to ore beneficiation equipment, the following are used to an increasing extent: hydraulic cyclones, Humphrey spirals, bow-shaped automatic launders, slime tables, electrostatic separators, magnetic separators, no-media grinding machines, etc. For example, at a certain alluvial tin mine, the average recovery rate has been raised 14% through the use of spiral separators in the place of the original launders. For the milling operations of a certain lead-zinc mine, hydraulic cyclones were used to aid regrinding of various middlings with the result that recovery was raised 1-2%. With regard to metallurgy, by using fuming furnaces to volatilize lead-zinc ore directly, the lead-zinc volatilization rate can reach 90%.

(c) There has been a development of flotation agents -- Investigations on the manufacture of flotation agents were made on the basis of utilization of indigenous raw materials, low production costs, and high efficiency. With regard to making "yellow acid salts," we employed the method of not using a diluting agent and instead produced a direct formation through vigorous stirring and low temperature conditions; products can be directly used without undergoing drying. A low solidification point fatty acid made from soybean oil as raw material is very suitable for use in ore dressing plants located in cold regions. The fatty acid made from soybean oil can be made into a further product, a sulfurized soap of fatty acid, which has the special characteristics of strong adsorption or collection properties and therefore low consumption; this product is particularly good when the water used is hard. If this reagent were used to float fluorite in hard water, the fluorite recovery rate can reach 92%, or 7% higher than recoveries obtained through reagents previously used. Through the use of an oxidized acetate fatty acid and oxidized rosin soap to float hematite, recovery of iron can reach 90%.

(d) There has been an improvement of production flowsheets and smelting and refining methods -- Much work has been done along these lines. For example, the use of sodium sulfide in beneficiating a mixed copper molybdenum (crude) concentrate enabled the recovery of 97-98% of the copper, 92-93% of the molybdenum, and 93-94% of the cobalt. Through employing a combination flowsheet of flotation and ammonia bath on difficult-to-beneficiate oxidized copper ore, copper recovery was raised about 30% over that achieved with simple flotation.

In smelting and refining, by improving smelting procedures in blast furnace operations, the recovery in crude lead has risen from the 90.9% in 1952 to 96% at present. By improving the quality of the charge and raising the temperature in the distillation retorts in the top, middle, and bottom sections, production from zinc retorts has been increased 40% over the original designed capacity and the zinc content of the residue has been lowered from 6-8% to 1.5%.

In the electrolysis of aluminum, on the basis of learning the Soviet method of lowering the proportion of sodium fluoride and aluminum fluoride, we studied the effect of additive agents on electrolytes. By using magnesium fluoride in the place of calcium fluoride as the additive agent, the melting point of the electrolyte can be substantially reduced. By making improvements on the electrolyte--raising the electric current density from 0.977 ampere per square mm to 1.05 ampere--the temperature of the electrolyte became slightly lower and the current efficiency was raised 2-3%. Aside from lowering the melting point of the electrolyte, the addition of magnesium fluoride helps to separate the carbon residue so that the consumption of aluminum fluoride is reduced 2 kilograms per metric ton of aluminum and the action of the electric current is better stabilized. Another technical development in the electrolysis of aluminum is that we have an operational method which substantially eliminates the anode phenomenon (reduced from the previous 1.5 to less than 0.03, and in some electric cells the anode phenomenon is completely eliminated). As a result of all these improvements, the average reduction in voltage is about 0.15 volt with corresponding lowering of electric energy consumption. More important, the efficiency of the mercury rectifiers has been raised; for the plants in existence, a 5% increase in the electric cells does not require installation of additional rectifiers.

### C. Increase Product Variety and Raise Quality

In 1952 our country's Ministry of Heavy Industry formally proclaimed standards for seven categories of alloy steel and related products, which totaled 159 alloy steel items. The standards issued were based upon Soviet standards; the types of alloy steel listed include primarily nickel-chrome steel items. In the early years of development, in order to learn from Soviet experience in the easiest manner and unify technical specifications, we pursued this policy of copying Soviet standards, which proved to be entirely correct with regard to attaining the objective of rapid industrial development. At the same time, we realize that our nickel and chrome resources must be further developed; as steel production rises and product variety increases, we have to establish a new alloy steel system suitable to our country's own mineral resources. Therefore, in 1953 we began research on nickel-chrome

substitute alloy steel products. During 1957-58, the Ministry of Metallurgical Industry, the China Academy of Science, and the First Ministry of Machine Industry on three occasions called special meetings to discuss problems related to substituting other metals for nickel and chromium in the making of alloy steels, and greatly pushed the investigations along these lines. In 1958, drawing from conclusions and experiences based upon the production and utilization of alloy steel in our country during recent years and learning from the advanced experience of the Soviet Union and the Democratic Republic of Germany, we first determined individual systems for special steels and finally, through considering the resources in our country, established a new integrated over-all alloy steel system. In the new system, we standardized 246 items of alloy steel products, divided temporarily into nine main categories: alloy structure steel, low-alloy high strength steel, alloy tool steel, high speed tool steel, rust and acid resistant steel, heat resistant and non-peeling steel and electric heat steel, low alloy steel rails, ball bearings, and shaft and bearings steel, and spring steel.

In recent years, we have made a number of new steel products on an experimental basis which contain either no nickel and chromium or have reduced amounts of nickel and chromium, including more than ten items within the above described nine categories that have already been placed in production. The development of the various categories of alloy steel products in our country is described roughly as follows:

1. Alloy structure steel -- In the new draft plans on standard items, there is no nickel alloy structure steel. In making machinery in the past, seven types of chromium and nickel-chrome steels that have been used to a great extent have been substituted by manganese steel, silicon-manganese steel, manganese-vanadium steel, boron steel, etc., so as to save chromium and nickel.

2. Low-alloy high strength steel -- In the new draft plans on standard items, there are thirteen steels belonging to the low-alloy high strength category that primarily use manganese, silicon, etc., as the main alloying elements; some special types of steel in this category also contain copper, aluminum, and titanium as alloying elements.

3. Alloy tool steel -- We have developed new items containing relatively little nickel, no chromium, and primarily silicon and manganese. For example, we used 60SiMnV to substitute in part for the uses of 55CrNiMo; also, in high speed steel we added silicon or molybdenum so as to save some chromium.

4. Ball bearing steel -- The use of carbon steels has been pushed. For example, we are employing 18CrMnTi, 20CrMnMo, and other alloys for making relatively high quality bearing and shaft steels. We are also studying presently used steel products of this category as to how to reduce the proportion of chromium and instead use alloying elements like silicon, manganese, etc.

5. Rust-proof steel -- The main objective is to save nickel and the measures taken are along the following three lines: (a) increase product variety and greater utilization of "iron element body" rust-proof steels; (b) push the use of rust-proof steels of the "Ao-ssu body" type which contain reduced amounts of nickel or no nickel, as for example the expanded use of Cr-Mn-N "Ao-ssu body" steels; (c) increase the production and utilization of "fu-ho" steel plates.

6. Heat resistant steels -- (a) Development of the "iron element body" and "pearl light body" types of heat resistant steels with a view to improving their heat resistant qualities has been promoted. For example, we made appropriate changes on the 12CrMoV steel, including adding other alloying elements, and we made a new heat resistant steel which at a temperature of 580°C and a load of 35 kilograms per square mm can withstand breakage for more than 700 hours. (b) To save chromium, we studied the possibility of coating hard chromium on low carbon tungsten-chrome-vanadium steel as a substitute for 1Cr13 as a material for making steam turbine blades. (c) Developed new heat resistant series of steel, as for example research on the three elements of Fe-Mn-Si. (d) Improved the properties of the Cr-Mn-C-N "Ao-ssu body" type of heat resistant steels, especially with regard to brittleness at high temperatures.

7. Non-peeling steel and electric heat alloy steel -- Eliminated the series on high nickel steels, and introduced a series of products containing elements like aluminum, silicon, titanium, chromium, etc. On the foundation of the Fe-Cr-Al electric heat alloys, investigations are made on using Fe-Al as a base but reducing or eliminating the chromium component in making better heat resistant alloys.

Under the leap forward production conditions in our country where new output potentials are steadily being developed, the problem of maintaining and improving product quality is complicated and difficult. To adjust to these conditions, the metallurgical workers in our country, ever since the beginning of the First Five-Year Plan period, have made special efforts to develop more favorable circumstances to cope with the problem. For example, the techniques related to determining the gas and impurity contents of steels are mastered and, in fact, improved; changes in hydrogen content of steels during the various production stages are being better understood; and improvements are made

in analytical and inspection methods with regard to steels and furnace residues. With regard to the problem of hydrogen content of steels, systematic investigations have been made to trace the source of hydrogen in the various stages of production and the distribution of hydrogen in the steel ingots; new specifications on the hydrogen content of steels were formulated. Results of investigations show that the process of solidification has a determining influence on the hydrogen content of the steel ingot, and the distribution of hydrogen in the "receding fire" /t'uei-huo/ steel ingot, aside from following the principle of dispersion, will also be affected by the compactness of the internal part of the steel ingot.

In the investigations on reducing deleterious elements in large size "boiling" steel ingots, we developed a method contrary to the traditional. The method involves the blowing in of oxygen or compressed air at the head part of the not yet solidified steel ingot to intensify the boiling action so as to remove a large proportion of the sulfur, phosphorus, and carbon; results achieved by this method are much better than those by the method of depressing "boiling" of steel ingots. As for the source of oxygen which serves to oxidize the deleterious elements in the steel ingot "boiling" operations, investigation results prove that what people formerly thought--that 70% of the oxygen comes from the air -- is basically correct.

In electric furnace smelting operations, the method of first ridding oxygen and then making reduced slag -- an integrated oxygen removal method -- has been further developed in our country. As applied to the smelting and refining of ball bearing steel, this method has cut the impurities in half while shortening the reducing period to less than 50 minutes. Investigations on the use of carbide to directly make the reduced slag prove that as long as the calcium carbide content is satisfactory and a "white slag" is assured during the reducing stage, the furnace slag or residue containing calcium carbide will not, like some research work has indicated, enter into the steel solution or melt and can, in addition, have a strong effect on sulfur removal.

Studies on the problem of lines developing in alloy steels have helped us understand the characteristics of these lines or cracks and the conditions under which they are formed. In line with the production conditions in our country, improvements have been made in methods of oxygen removal, shape of ingot dies, and further processing procedures; as a result, the problem of lines developing in certain alloy structure steel has entirely been solved. By introducing a series of measures, such as blowing in of oxygen in smelting and refining, improving reducing or reduction operations, adding titanium-iron before steel is turned out, raising the temperature of producing steel and the casting temperature when possible, enlarging the forms for steel



ingots, and reducing thickness of the forms, the lines in high chromium non-rust steel can be greatly reduced and the ratio of steel materials made according to specifications can reach more than 90%. The results of investigations also point out that, for high chromium non-rust steel refined and cast under vacuum conditions of 30 mm mercury pressure or less, the lines can be entirely eliminated.

Regarding the problem of fine crystals formed in high alloy steels, the addition of small quantities of titanium to iron-chromium-aluminum alloys very clearly improves the crystal formation phenomenon of the ingots and greatly reduces cracking in hot tempering. At the same time, the aluminum content of the above described alloy is raised and when the alloy is drawn into wire the recovery in finished products can attain more than 60%; the alloy when tested for "life" under standard conditions can maintain its strength at 1,170°C for more than 200 hours. With regard to rust-proof heat resistant steel, methods to improve the consistency of the steel ingots in terms of fineness and homogeneity of the crystals include employing a "yin-yu" agent, adding of rare earth alloys or rare earth oxidized materials, and the use of the vibrating casting method. For example, we tried to eliminate or reduce unsystematic crystallization in 18Cr<sup>W</sup>IV steel. The use of supersonic techniques has been started; not long ago a large scale supersonic vibrating installation (50 kilowatts and 20,000 frequency) was made on a trial basis in our country. Some preliminary conclusions have been drawn from experiments in steel plants to make finer crystal ingots, to eliminate occlusions of gas in steel, and to reduce carbonaceous materials.

In silicon sheet steel, by using vacuum processing, vacuum casting, and heat application methods, we have made on a laboratory scale basis a hot rolled silicon sheet steel of 0.35 mm thickness which has an iron loss of  $P_{10} = 0.68 - 0.73$  watt per kilogram. At the same time, we have made a cold rolled silicon sheet steel of 0.06 - 0.08 mm thickness, which has a "ch'u-hsiang-tu" /ch'u means take, hsiang means direction, and tu means degree/ of 94% and a "two peak" ratio of 1.25 for the magnetic torque curve. Work on the above projects is being done on a larger scale so that these and other methods can be eventually employed in production.

Converter steel occupies an important position in our country. We have adopted automatic recording and automatic control to improve converter operations, especially with regard to product quality. Various research units in our country have jointly conducted investigations on this subject and have formulated and made on a trial basis a series of systems and instruments, including the following items: (a) use of the ultra red radiation high temperature instrument to determine and automatically record flame and steel melt temperatures; (b) use of the

"double color" high temperature instrument and its "w" curve method to determine when to stop blowing in air or wind (control of end point of blowing and high carbon stoppage of wind); (c) adoption of the French "Volume Debitgraph" air or wind volume determination and recording method (which also records accumulative air quantity); (d) use of a supersonic "liquid surface" instrument and wind-pressure type "liquid surface" instrument on a comparative basis to determine the "kang-shui yeh-mien" [steel water liquid surface]; and (e) use of alternating current electric bridge installation and secondary instrument to automatically record the tipping angle of the converter, the accuracy of which is  $\pm 0.5^\circ$ . The practical application of these control systems and instruments are in the process of investigation.

From the above it is seen that the advance of metallurgical science and techniques in our country during the last ten years has been very rapid and the achievements have been great. Although the army of workers in metallurgy are still relatively young, they have already successfully assumed the responsibilities of construction and development assigned to them by the country and, at the same time, achieved results of a revolutionary nature. The main reason for this success is the correct leadership of the Party and the superiority of the socialist system. The sincere and unselfish help given by brother socialist countries, particularly that given by the Soviet Union, is part of the whole picture.

Although we have achieved outstanding results during the last ten years, our work has a number of weak sectors when viewed on the overall basis of metallurgy and in some fields levels in our country are still at a definite distance behind those of advanced countries. We believe, however, that under the correct leadership of the Chinese Communist Party and in line with the rapid progress of socialist construction in general, the technological level of metallurgy in our country will advance further at a very rapid pace so that one will find, in the world treasure house of science and technology, more and more contributions from our country.